PAGE 1 (Cover)

NASA's Earth Science Division Research and Analysis Program

PAGE 2 (Inside cover, LT side) – Pretty Earth image and R&A overview

Explaining Earth Observations

NASA's Earth Science Research and Analysis (R&A) program collects and analyzes data from Earth-observing satellites, airborne campaigns and surface-based instruments. It then uses these data to advance our scientific understanding of Earth as a system and to improve our ability to predict its response to natural and human-induced changes.

PAGE 3 (Inside cover, RT side) – R&A overview

Advancing Earth science

The R&A program supports and works with NASA scientists, domestic and international partners, academic institutions, nonprofits and other government agencies to conduct high-level research through large-scale satellite missions, targeted field campaigns, data analysis and advanced scientific computing. These data complement, calibrate and validate satellite observations and provide real-world inputs for quantitative models that detect and predict conditions on Earth.

The R&A program achieves these goals through key programmatic elements, including:

- **Satellite data records:** Provide detailed scientific observations on global and regional scales to advance our understanding of Earth as an integrated system.
- **Airborne science:** Enables scientists to test new measurement approaches, collect detailed *in situ* and remote-sensing observations to investigate processes, and provide calibration/validation information for satellites.
- **Surface-based measurements:** Provide unique observational capability that complements satellite measurements and provides calibration, validation and algorithm testing capability.
- **Modeling:** Offers a best estimate of the current state of components within the Earth system and the mechanisms that couple them, including short-term forecasts that support field missions and longer-term forecasts that assess Earth's response to various drivers of change.
- **High-end scientific computing:** Converts satellite observations into scientific data products and synthesizes long-term data sets to provide initial and boundary conditions, validation and verification references, and internal and external constraints for scientific models.

PAGE 4 and 7 (outside pages of gatefold) – Focus areas

Atmospheric Composition

The Atmospheric Composition focus area improves our understanding of the composition of Earth's atmosphere, especially the troposphere and stratosphere, as it relates to climate, ozone, aerosol particles, solar radiation, air quality, surface emissions of gases and particles and atmospheric chemical processes.

Weather

The Weather focus area researches the dynamics and thermodynamics of the atmosphere and its interaction with the oceans and land, ranging from local processes to global-scale phenomenon and lasting from minutes to a season.

Climate Variability & Change

The Climate Variability & Change focus area supports research and analysis of satellite, aircraft and ground-based observations to determine the roles played by the oceans, ice, land and atmosphere within the Earth's climate system.

Water & Energy

The Water & Energy Cycle focus area studies the distribution, transport, and transformation of water and energy, including the dynamics of extreme weather events such as droughts and floods. The focus

area employs and improves remote sensing techniques to collect and interpret measurements on global precipitation, snowpack, soil moisture, water quality, evaporation, surface water and groundwater.

Carbon Cycle & Ecosystems The Carbon Cycle & Ecosystems Focus Area conducts research that helps detect and predict changes in the Earth's terrestrial and marine ecosystems, including biogeochemical cycles, land cover, biological diversity and regional and global carbon cycles.

Earth Surface & Interior The Earth Surface & Interior focus area supports research and analysis of solid-Earth processes and properties from crust to core. This includes providing the space geodetic observations and products foundational to many space missions.

PAGE 5 and 6 (inside pages of gatefold) – Anecdotes

NASA's Earth Science Research and Analysis program sponsors research pertaining to six key focus areas, which are listed here along with some examples of how R&A is advancing Earth science:

Observing atmospheric impacts of the Clean Air Act. The National Ambient Air Quality Standards within the Clean Air Act place restrictions on pollutants, including NO_2 from cars and power plants, that can be emitted into the atmosphere. Using data from the **Ozone Monitoring Instrument (OMI)** aboard the Aura satellite, scientists funded by NASA's **Atmospheric Composition focus area** found that NO_2 levels over the United States decreased by 20-60% from 2005 to 2014, shedding more light on the relationship between pollution and our atmosphere.

Solving the mystery of hurricane intensification. Although scientists have significantly improved the ability to predict when and where hurricanes will strike, it is still difficult to predict their intensity. Research funded by NASA's **Weather focus area** seeks to understand what makes hurricanes intensify and weaken. Data collected during the **Hurricane and Severe Storm Sentinel (HS3) airborne campaign** contradicted previously held beliefs that asymmetric storm systems and the presence of dust automatically weaken hurricanes. This new information will improve forecast models and aid in our ability to predict storm strength in the future.

Redrawing the map. In July 2017, approximately 2,240 square miles of ice—nearly the size of Delaware—broke off the Larsen C ice shelf in Antarctica and drifted into the Southern Ocean. NASA's airborne **Operation IceBridge**, funded by the **Climate Variability & Change focus area**, had observed the rift firsthand in November 2016, and imagery from **MODIS on NASA's Aqua satellite** confirmed the final rupture.

Tracking water during drought. From 2014-2016, up to 60% of California suffered from "exceptional drought". During that time, research funded by NASA's **Energy & Water Cycle focus area** helped scientists and communities better understand the distribution of freshwater throughout the state. Data and model output from NASA's **Airborne Snow Observatory campaigns** and **GRACE satellite mission** revealed where freshwater was previously stored, estimates of drought severity, and how groundwater levels were subsequently affected. These data and more help scientists gain a more holistic understanding of the water cycle during times of drought.

Mapping forest evolution. Researchers funded by NASA's **Carbon Cycle & Ecosystems focus area** developed a way to tell a tree's age from space. Using a lidar-based mapper during the **Arctic-Boreal Vulnerability Experiment (ABoVE) airborne campaign**, scientists found that tree height, which can be accurately measured with lidar, correlates with tree age. These data can be used to create large-scale maps showing changes in the structure and spatial distribution of forests as northern climates continue to warm. These changes affect wildlife habitat, climate feedbacks and hydrological and biogeochemical cycles.

Imaging induced earthquakes. Researchers funded by NASA's **Earth Surface and Interior focus area** have demonstrated a way to image human-induced earthquakes using radar satellite data. Scientists used **interferometric synthetic aperture radar (InSAR) technology** to create images and detect the propagation of faults deep underground after a magnitude-5.8 earthquake struck Pawnee, OK. They then used the images to determine the source of the earthquake and demonstrate that it was consistent with the injection of wastewater related to

petroleum operations, rather than natural processes. InSAR can help scientists better understand what conditions are necessary for faults to slip and ultimately cause earthquakes.